Energy, Policy, and Ecosystems Services on a +11 Billion Person Planet: What’s Ahead?

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From: World Population Stabilization Unlikely This Century
Energy, Water, Land on a +11-billion Person Planet...

Earth
Daytime Polar View (North)
MODIS Composite
Urbanization - as a process - impacts ecosystems directly and indirectly.

How do we address the complex interactions between the human and natural Earth systems in such a way that we can better determine our own destinies?
Global Land Cover
Pre-Agriculture
Approx. 10,000 BCE

% of Land Area Transformed for Agriculture (Negligible)

World Population
6 - 10 Million
Global Land Cover

Post-Agriculture

Present

43% of Land Area
Dominated by Agriculture

World Population
6.5 Billion
Global Land Cover
Urbanization

Present

% of Land Area
Built-up
3 - 6%

World Population
6.5 Billion

GIS overlay of processed Nighttime city lights data on soil productivity maps
China to Flatten 700 Mountains to Build a City / TIME.com
Consequences of Urbanization on NPP

Satellite Observations

DMSP/OLS Urban Map
Urban, Peri-urban, Non-urban

AVHRR/MODIS
Monthly NPP (g C m\(^{-2}\))

NPP and Local Climate:
Urban Heating Extends Length of growing season locally in cold climates.

Winter NPP gain negated in peak season by reduced vegetation and heat stress.

Seasonal Offset diminishes in tropics

In semi-arid regions cities enhance NPP relative to surrounding areas

M. Imhoff et al., RSE 89 (2004) 434–443
Consequences of Urbanization on NPP-Carbon in the U.S.

**Urbanization and NPP**
- NPP decreased 41.5 M tons C / year.
- Roughly equivalent to the increase created by 300 years of agricultural development.

How can this happen when urban areas occupy only 3% of the land surface and agriculture occupies 29%?

**Location, Location, Location.**
*Urbanization is taking place on the most fertile lands*

Reduction of NPP may have biological significance:

<table>
<thead>
<tr>
<th>NPP Lost or Gained (annual)</th>
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<tbody>
<tr>
<td>Due to Urbanization</td>
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<tr>
<td>Going from a pre-urban to a post urban world</td>
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**Total Reduction**
- 41.5 Mt C

**From Ag Lands**
- 25.5 Mt C

M. Imhoff et al., RSE 89 (2004) 434–443
Human Consumption of NPP: Can the Earth Keep Up?

NPP Carbon Balance

Planetary Supply

Human Demand

Balance

M. L. Imhoff et al., Nature 429, 870, 2004
M. L. Imhoff et. al., JGR, VOL. 111, 2006
Geography of Food Energy: Human Appropriation of NPP (HANPP) as % of Terrestrial Supply

Some regions exceed their local capacity by many times.
Food security dependent on trade.

North America 29%

South America 8%

W. Europe 86%

S. Central Asia 96%

300%

M. L. Imhoff et al., Nature 429, 870, 2004
M. L. Imhoff et. al., JGR, VOL. 111, 2006
Will human consumption of primary plant production soon reach its limits?

Terrestrial net primary (plant) production provides a measurable boundary for human consumption of Earth’s biological resources.

Satellite observations of planetary NPP “Supply” shows no trend but human “Demand” is rising.
What Are the Real Limits and Sensitivities of the System?

- Snapshot based analyses of HANPP or other resources are not adequate to understand the limits and associated trades available to overcome them.

- A systems based approach that can account for the interactions of the Earth and Human systems is needed.
  - Products must be “dynamic” and capable of both hindcasting for uncertainty analyses as well as have prognostic capability for testing potential outcomes of choices (sensitivity).
  - Critical for policy evaluation!
Integrated Assessment:
Energy, Water, Land, Demographics, Economics, Technology, Policy, Climate - fully coupled in a single model

PNNL’s Global Change Assessment Model (GCAM)

- GCAM is a **global integrated assessment model**
- GCAM links **Economic**, **Energy**, **Land-use**, **Water** and **Climate** systems
- Technology-rich model
- Emissions of 16 greenhouse gases and short-lived species: CO₂, CH₄, N₂O, halocarbons, carbonaceous aerosols, reactive gases, sulfur dioxide.
- Runs through 2095 in **5-year time-steps** – soon **1 year time steps**
- GCAM has participated in virtually every major climate/energy/economics assessment over the last 20 years
- Globally, there are roughly six IA teams with RCP-class IA models
- GCAM is a community model
- Documentation available at: [wiki.umd.edu/gcam](http://wiki.umd.edu/gcam)
GCAM’s Adaptive Spatial Resolution

- 32 Energy Economy Regions
- 283 Land Regions
- 233 Water Basins
- 50-State Energy Economy Regions
- Grid-Level Water, Energy, Land, and Emissions
Integrated Assessment means complex relationships are retained. Global drivers and regional outcomes.

These systems can get very complicated very quickly.
GCAM allows for fully integrated inquiry and “What if” Scenarios

► How will growth and changes in the global demand for energy, water, and agricultural goods affect each other and impact stability?

► What are the factors that drive these changes?
  - **Energy sources, Technology** (generation, conversion, transmission), **Socio-economics** (economics, demographics, and migration), **Policies** (national and multinational), **Water scarcity, Food production and prices**, **Climate** and **extreme weather**.

► How do these drivers interact (+ or - feedbacks)?

► **Who “wins”? Who “loses” if….?**
  - Simple questions. Complex answers!
Global Energy Portfolio (Primary Energy) to Meet a 550 ppmv CO₂ target by 2100

From CCSP Product 2.1a: Scenarios of Emissions and Greenhouse Gas Concentrations
How do climate change polices affect fossil fuel and agriculture prices?

**CO₂ Concentration**

- **Tax ($10/tC in 2020)**
- **Reference**

**Global Mean Temperature Rise**

- **Tax ($10/tC in 2020)**
- **Reference**

**Coal Price**

- **Reference**
- **Tax (10$/tC in 2020)**

**Wheat Price**

- **Reference**
- **Tax (10$/tC in 2020)**
How Much Food Will We Need?

- Global agricultural economic modeling for AgMIP
- Model comparison among leading models
- Harmonized reference case and both climate impacts and bioenergy scenarios

Results projected to 2030 and 2050

Future world agricultural production (feed and food) needed compared to 2005
Energy policy can have surprising feedbacks with land cover and climate forcing!

Taxation policy favoring biofuels raises food prices, decreases coal prices, accelerates deforestation, and slows down climate warming due to raised surface albedo.

Fossil Fuel Only Carbon Tax resulted in nearly 50% deforestation

Higher albedo = cooling!

A. Jones et al. 2012
Water Impacts: Current Results

Many parts of the world will face more scarcity in the future, largely driven by changes in demand.

Future water demands depend heavily on socioeconomic developments.
Water Impacts: Key Research Directions

Climate change will affect hydropower generation, which in turn affects other electricity generation.

Positive values mean an increase in electricity generation when impacts are considered.
Water Impacts: Current Results

Humans play a larger role in water scarcity in 93% of the basins (89% of total land)
Urbanization in the Anthropocene: What's Ahead for Food Security, Energy, and Climate?
Spatial extension (global urban mapping)
An online modeling and visualization system

Province: Beijing

urban in year
1.992 to 2.012

Run Regional Modeling
Run Spatial Modeling
Run Projection


2012

2015

2020

2025

http://terpconnect.umd.edu/~yuyuzhou/urbanization.html
Climate change reduces overall energy use for some areas but shifts pressure onto cooling in the building sector resulting in an added demand for electricity in megacities.

(Source Zhou, 2013)
Regional Downscaling of GCAM: Provides Insights about Regional and ‘Local’ Impacts of Global Forcings

Climate Impacts on Building Energy Use

Fixed Climate

A2 Climate
Fully understanding the interaction of ecosystem services, climate, and human action requires integrated approaches at various spatial and temporal scales.

Integrated assessment models need to be supported by high quality data and process understanding that are vetted and consistent across the user communities.

The interoperability of IAMs with other models can be enabled by developing spatially explicit representations of important “shared” elements such as specific land cover/land use types or infrastructural features (e.g., location and extent as well as infrastructure type, location, and density, and population and demographics) that link to IAV models and tools.

Urbanization as a multifaceted entity is one such example

IAM’s have demonstrated that policy matters if consistently and widely applied and that results can be surprising.
Acknowledgment

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- DOE Integrated Assessment Research Program through the iHESD SFA and RIAM projects
- PNNL Platform for Regional Integrated Modeling and Analysis (PRIMA) Initiative
The Carbon Cycle

Primary Production is critical part of the carbon cycle for human existence

Vegetation and its phenology has immediate impact on atmospheric CO$_2$
Earth’s “Bio-Engine”
Net Primary Production (NPP)

NPP is the amount plant material produced on Earth. It is the primary fuel for Earth’s food web. Represents all available food and fiber.

NPP can be measured in terms of Carbon
(photosynthesis - CO2 exchange between atmosphere and biosphere (global climate change).

Land use strongly impacts NPP
Humans require almost 20% of Earth’s NPP capacity on land

NPP is the “Common Currency” for Climate Change, Ecological, & Economic Assessment.
Example of end-to-end interaction in GCAM

“What if a global policy favoring biofuels was implemented and ran out to 2100?”
Agriculture Impacts: Current Results

Including climate change impacts results in an increase in global food & fiber area

![Graph showing the increase in global food & fiber area from 2005 to 2095 under different RCP scenarios with and without impacts. The graph displays the area in millions of km², with RCP8.5, RCP6.0, RCP4.5, and RCP2.6 scenarios, with and without impacts.]